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Current sharing of paralleled DC–DC converters using GA-based PID controllers

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ABSTRACT

We demonstrate a concept for pulse-width modulation (PWM) control of a parallel DC–DC buck converter, which eliminates the need for multiple physical connections of gating/PWM signals among the distributed converter modules. The proposed control concept may lead to easier distributed control implementation of parallel DC–DC converters and distributed power systems.

For equipment with significant power requirement, the traditional single power supply may not be adequate. Many power supplies with parallel regulation control can be used to solve this problem. This paper proposes a Proportional-Integral-Derivative (PID) controller to control paralleled DC–DC buck converters and current sharing is achieved. A genetic algorithm (GA) is employed to derive optimal or near optimal PID controller gains. Both simulations and experimental results are provided to verify the theoretical analysis through an experimental prototype of paralleled DC–DC buck converters.

1. Introduction

Two or more power stages in a single DC–DC converter can be connected in parallel to increase output power level. When paralleling DC–DC power converters, each paralleled converter has its own dedicated voltage regulation controller. Each converter can operate either stand-alone or in parallel to fulfill the requirements of current sharing. While a DC–DC converter contains paralleled power stages, normally only a single voltage loop is implemented for the converter voltage regulation.

Current-sharing parallel DC–DC converters potentially offer several advantages over a single stand-alone unit in terms of modular architecture, reconfigurability, redundancy and fault tolerance, and cost (Mazumder, Tahir, & Acharya, 2008). In order to obtain the goal of current sharing, the current share scheme must be designed within DC–DC converter. Many studies have focused on the modelling and dynamic control of the paralleled DC–DC converter to stabilize current share loop.

One of the commonly used methods, for stabilization of parallel DC–DC converters, is the conventional droop method (Jamerson & Mullet, 1994; Mazumder, Tahir, & Kamisetty, 2005). Droop method, which yields high system redundancy, can be accomplished with several classes of converters. To minimize the negative effects of conventional droop and for increased reliability, paralleled DC–DC converters require an active-current-sharing mechanism to ensure even distribution of currents and stresses between the modules. The essence of current sharing is to monitor the difference between the reference current and the output current of each converter and incorporate this information into the control loop.

The droop, average and master-slave current share schemes are frequently used in DC–DC converter. No matter what kinds of current share schemes are used, the resulting current share control effort must be added on to the referent command or the output voltage must be modified via the feedback voltage to obtain equal current share among the DC–DC converters. The GA-based PID controller is proposed in this paper to obtain current-sharing control of parallel connected buck converters.

Finding control gains, which minimize or maximize a designated cost function in time domain subject to multiple constraints specified by frequency-domain specifications, becomes a complex, constrained optimization problem. The problem is so complex that it cannot be analytically or numerically solved. Fortunately, recent applications in genetic algorithms (GAs) reveal a way to resolve the problem (Goldberg, 1989; Hwang, Kim, & Lee, 2008; Tan, Lu, Loh, & Tan, 2005). Considering many points in the search space, a GA has a reduced chance of converging to the local optimum and more likely converges to the global optimum. GAs have been applied in system identification and adaptive control of both continuous- and discrete-time, decentralized PID control, as well as to the optimal control problems (Chen, Kuo, Yan, & Lia, 2009; Lin, Jan, & Shieh, 2003). They have also been successfully applied in different areas such as power quality assessment (El-Zonkoly, 2005), and adaptive scheduling system (Juang, Lin, & Kao, 2007).

The rest of this paper is organized as follows: Section 2 presents a GA-based PID controller design. The stability analysis is illustrated in Section 3. Section 4 shows the experimental results that demonstrate the performance of the control scheme. Finally, brief conclusions are provided in Section 5.

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Table 1
Parameters of buck converter system.

Nominal parameters	Values
Inductance, L	50 μH
Output Capacitance, C	470 μF
Resistance of inductor, r_L	0.021 Ω
Resistance of Capacitor, r_C	0.021 Ω
Load resistance, R_L	2 Ω
Input voltage, V_{in}	15 V
Reference voltage, V_{ref}	5 V
Switching frequency	10 kHz

Table 2
The parameter settings of GA.

	Number of first generation	Cross rate	Mutation rate
Quantities	24	0.9	0.03

2. A GA-based PID controller design

GA is an artificial optimization scheme developed in analog to natural evolution performing an exploration of the search space. It has been considered as an efficiency technique for searching the global or near global solution of complex optimization problems. The procedure of GA contains six parts: initialization, evaluation, statistics, reproduction, crossover, and mutation. The learning process based on GA is described as follows (Nakayama et al., 2001):

Step 1 : Generation of initial population of individuals.
Step 2 : Learning individuals.
Step 3 : Evaluation of fitness of the trained individuals. If the highest fitness satisfies the threshold, then stop the learning, otherwise go to Step 4.
Step 4 : Selection of dominants having high fitness.
Step 5 : Generation of new individuals through crossfertilization, natural selection and mutation using the dominants above. Go to Step 2.

Table 3
The parameters of PID controller.

Parameters	K_P	K_I	K_D
Initial values	−10000 ∼ 10000	−10000 ∼ 10000	−10000 ∼ 10000
After trained	5.3294	1.5927	0.3927

There are many methods that provide PID Controller tuning. It is necessary to know the controller's configuration before re-tuning. The parameters of buck converter system are shown in Table 1. The parameter settings of GA are shown in Table 2. The tuning process is implemented by MATLAB as shown in Fig. 1. The optimal values of K_P, K_I, K_D are obtained through this procedure as shown in Table 3.

3. Stability analysis

To verify the stability of the PID controller, the Bode plot and the root locus are used to investigate the stability and margin of the system (Li & Lehman, 2004; Ayyanar, Giri, & Mohan, 2004). Fig. 2 shows the schematic of power stage of the buck converter.

The control-to-output transfer function of open-loop system is as shown

$$G(s) = \frac{V_0(s)}{D(s)} = V_{in}\frac{(1 - sr_CC)}{LC\left(s^2 + s\left(\frac{1}{R_LC} + \frac{r_C + r_L}{L}\right) + \frac{1}{LC}\right)} \quad (1)$$

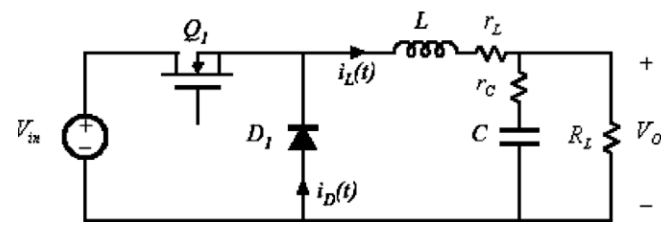

Fig. 2. Circuit diagram of the converter.

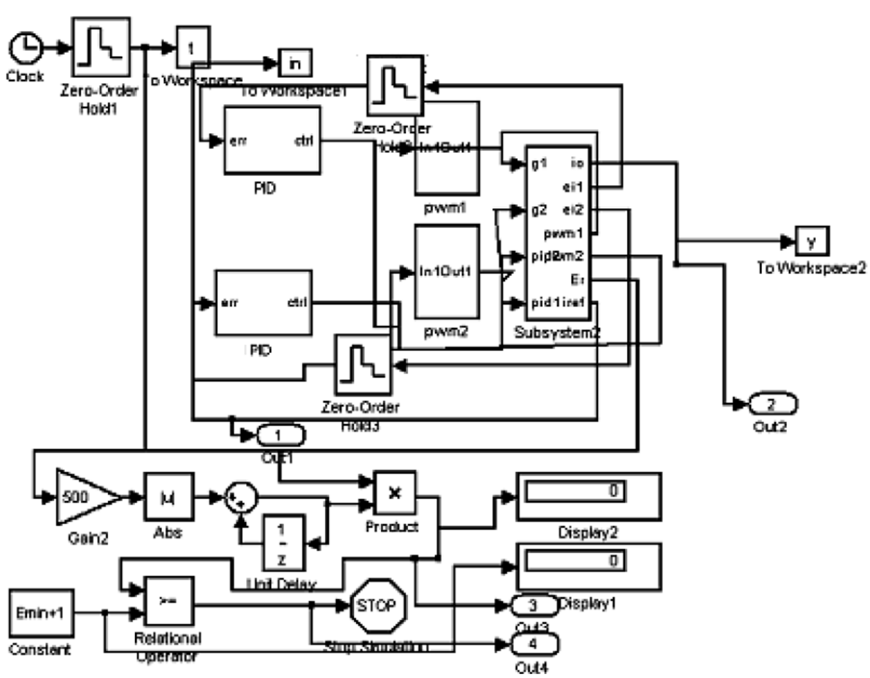

Fig. 1. The controller with GA.